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SciVerse ScienceDirect
Procedia Environmental Sciences 12 (2012) 823 – 830
Procedia
Environmental Sciences

2011 International Conference on Environmental Science and Engineering

(ICESE 2011)

GIS and RS based Assessment of Cultivated Land Quality of Shandong Province

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Abstract

Cultivated land resources are the material foundation that mankind rely on for existence. The change of quantity and quality is directly related to national food security and social stability. Based on the RS and GIS technologies, this article took Shandong Province as the study area and the years of 2000 and 2005 as the study period and made use of the MODIS product data to assure the simultaneous research of the large-scale area. After collecting and sorting out the methods and indices about cultivated land assessment at home, the Pressure-State-Response Model (PSR) was adopted, and slope, light-temperature potential productivity, NDVI, TVDI and unit yield were chosen as the assessment indices. Each index was given weight by using the expert evaluation method and the cultivated land quality was then calculated. Through the analysis of the assessment results, three conclusions were drawn. First, the overall quality of the cultivated land in Shandong was relatively high. Second, the quality of the cultivated land in Shandong generally decreased from the southwest to the northeast except that the land in the middle was the lowest. Third, the overall cultivated land quality of Shandong slightly declined during the years from 2000 to 2005.

*Keywords :*Cultivated land quality, GIS, RS, Shandong Province

1. Introduction

Cultivated land is one of the most important parts of land resources and material foundations that mankind rely on for existence. Its quantity and quality are directly related to the agricultural development and food security of certain area (Zhang, Liu, Zhang, Jiang, 2008). China's actual condition leads to the fact that cultivated land plays a decisive role in national economy and social development (Zhang, 2004).

 doi:10.1016/j.proenv.2012.01.354

With the rapid economic development, urbanization and industrialization, however, limited cultivated land is being occupied continually and exploitable land resources are finite so that the situation of cultivated land in the future is extraordinarily severe. In recent years, the change of cultivated land caused by human activity exerting an impact on ecological environment and human life has been concerned by more and more people (Hao, Chang, Ning, 2003). In order to protect the cultivated land resource and improve its quality, it is essential to investigate and assess the cultivated land quality (CLQ) objectively (Fang, 2007).

The assessment of CLQ is the process of estimating the productive potential and suitability of cultivated land, through which it is possible to reveal the spatiotemporal variation of land quality and understand the mechanism and process of regional environmental change induced by economic human activities, so as to protect the cultivated land resource, improve the management policy and promote the sustainable use of cultivated land. Besides, the result is necessary for departments and institutions concerned with making the agriculture and land policy, particularly in China today where both food security and agricultural produce quality are closely related to CLQ.

Monitoring and assessing the CLQ at the regional scale immediately requires the quantifiable and cost-efficient data. An ideal source of such data is satellite imagery, from which it is possible to get the real-time information used for assessing CLQ. Moreover, powerful spatial analysis function of GIS makes CLQ assessment more objective, scientific and accurate. In most cases, TM or MSS imagery as the data source of cultivated land investigation based on RS is used in extracting cultivated land information in a small-scale region, for it has a high resolution. However, assessing CLQ by using remote sensing imagery is numerable, especially in large-scale region. This study aims to build a CLQ assessment model based on RS and GIS in a large-scale region. Thus, MODIS imagery with 1km-resolution has been chosen to calculate the indicators used for CLQ assessment. Take the case of Shandong Province. Analysing the spatiotemporal variation of its cultivated land quality, this article is quite meaningful for promoting the sustainable use of cultivated land in study area.

2.Study area and Methodology

2.1.Study area

The study area is Shandong Province situated on the eastern coast of China, which is in the lower Yellow River valley. The Shandong Peninsula in the east protrudes between the Bohai Sea and Yellow sea from the land mass and faces the Liaodong Peninsula in the north across the Bohai Straits, while the inland in the west is adjacent to Hebei Province, Henan Province, Anhui Province and Jiangsu Province from north to south orderly. It extends from 114°19′E to 122°43′E and from 34°22′N to 38°23′N, covering a total area of 156,700 km^2, 1.6% of China. The area has a warm temperate monsoon climate with a mean annual temperature of a range from 11℃ to 15℃ and a mean annual precipitation of 710mm. In addition, more than a half area in Shandong province is the plain suitable for cultivating. All of these natural conditions mentioned above are favourable for the development of agriculture.

Fig.1 The study area of Shandong Province, East China.

Shandong Province is one of China's major agricultural production bases, well known as "a warehouse of grains, cotton, and oil, and the land of fruits and aquatic products", where the cultivated land resource is abundant. Nevertheless, cultivated land area per capita is scarce, which is 0.0823hm^2 less than the average national level 0.094hm^2 in 2004. With the rapid economic growth, the quantity of cultivated land decrease gradually. It decreased by 131,900hm^2 from 2001 to 2004, which was caused by both human activities and natural factors, such as the occupancy of construction land, the adjustment of agricultural structure and disastrous destruction. The overuse of the agricultural chemicals and the shortage of reserve land resource make CLQ more severe. So that the assessment of CLQ is required for the purpose of preventing cultivated land degradation.

2.2.Methodology

In this article, the pressure-state-response framework used to structure and classify information was adopted for the reason that a single index of land quality is neither feasible nor reasonable but groups of indicators can be used to reflect the land quality comprehensively. The indicators representing land quality was selected from three different aspects: pressure on the land resource (PLI), state of land quality (SLI) and societal response (RI). First of all, to a certain degree, cultivated land productivity is restrained by its natural conditions described as pressure in the framework mentioned above so that the higher pressure cultivated land is under, the worse CLQ we get. Secondly, the state of land quality reflects the conditions of land as well as its resilience to withstand change as a consequence of sector pressures. Thirdly, under the natural pressure, with the current state, cultivated land responds with indicators as a result of all of these influences. Besides, the response mechanisms are normally involved with human activities which could be indicated by statistics data. Each of the three perspectives is considered equally important to CLQ, hence has the same weight:

$$CLQ = (PLI+SLI+RI)/3$$

Two indicators of **slope** and **light-temperature potential productivity (LTPP)** are selected to represent the pressure on the cultivated land. The slope influences not only the irrigation of land and the use of farm implements, but the water and soil conservation as well. As a result, the slope with a steeper gradient leads to a lower cultivated land quality. The appropriate sunlight and temperature are the basic demand for crop growth, restraining the potential productivity of cultivated land. The indicator of light-temperature potential productivity was used to measure whether the condition of both light and temperature are enough good for crop to grow.

Apart from slope and condition of light-temperature, soil fertility and soil moisture representing the current state of land resource should also be considered as indicators of CLQ assessment. Normalized difference vegetation index (NDVI) obtained from MODIS imagery not only is one of the most successful of many attempts to simply and quickly identify vegetated areas, but also detects the live green plant canopies, thereby reflecting the soil fertility in counterpart area indirectly. Soil moisture studied via temperature-vegetation dryness index (TVDI) is reflective of the condition of precipitation and irrigation.

The unit yield of an area is the general response to cultivated land quality and the most direct performance of its cultivated land quality. In sum, 5 indicators listed above are selected to assess CLQ of Shandong Province in three ways: pressure, state and response.

3.Derivation and Grading of assessment indicators

3.1.Derivation of assessment indicators

In order to analyze the temporal variation of cultivated land quality, cultivated land of 2000 and 2005 were selected respectively to be compared. The pressure on the land resource mainly depends on natural settings and climate conditions, the temporal variation of which between 2000 and 2005 is infinitesimal so that it could be neglected. As a result, slope and light-temperature potential productivity only need to be calculated once during the study period.

(1) The index of slope was calculated by using software ArcGIS9.2 with 1:1,000,000-scale DEM data.

(2) Radiation potential productivity (RPP) is required for calculating the light-temperature potential productivity. From the perspective of the condition in China and the data source, a modified coefficient (0.219) proposed by Huang Bingwei (1985) was selected and used to convert the gross radiation intensity (GRI) into the radiation potential productivity.

$$RPP = 0.219 \cdot GRI$$

Gross radiation intensity is related to many factors including sunshine hours, percentage of sunshine, mean annual cloud cover, mean annual absolute humidity, elevation and latitude. The correlation analysis of all these factors resulted in a formula with three factors:

$$Q=170292+20.73 \cdot hours-0.19 \cdot hours \cdot \Phi+0.07 \cdot H \cdot \Phi$$

Where **Q** denotes gross radiation intensity (0.01trillionJ/m^2), **hours** denotes annual sunshine hours (0.1h), **H** denotes elevation (0.1m), Φ denotes latitude (degree).

Based on radiation potential productivity, the temperature model by Tian Yongzhong was adopted to calculate the light-temperature potential productivity (LTPP).

$$LTPP = f(T) \cdot RPP$$

$$f(T) = 1 / (1+e^{2.052-0.161T})$$

Where ***f(T)*** denotes temperature coefficient, **T** denotes annual temperature.

(3) NDVI were downloaded from the official website of National aeronautics and space administration (NASA) for free and the data products has been derived from atmosphere corrected, bidirectional red, near-infrared, and blue surface reflectance that are masked for water, clouds and cloud shadow. In this study, the NDVI data of Shandong Province from April to August in both 2000 and 2005, which is the time when crops keep the highest canopy, were extracted.

(4) Enhanced vegetation index (EVI) and land surface temperature (LST), the preprocessed products, which could be downloaded from the official website of NASA as well, are two basic factors for calculating TVDI. In this study, EVI data and LST data with the same period as those in NDVI were selected.

Scientists (Price, Carlson, Sandholt, Moran et al) have proved that land surface temperature and vegetations index are correlative so that indices LST and EVI were selected to construct the space of LST-EVI. It led to the definition of the TVDI as expressed below:

$$TVDI = (Ts-Ts_{min}) / (Ts_{max}-Ts_{min})$$

Where Ts_{min} is the minimum LST given the EVI along the wet edge (℃), Ts_{max} is the maximum LST given the EVI along the dry edge (℃).

As a result, a region with higher TVDI is drier than that with lower TVDI.

(5) The unit yield of every city in Shandong Province in both 2000 and 2005 were obtained from statistical yearbook of Shandong Province 2001 and statistical yearbook of Shandong Province 2006 respectively.

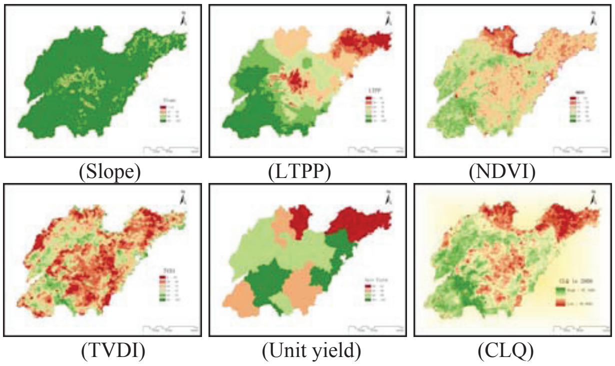

Fig.2 Thematic maps of indicators and CLQ in 2000

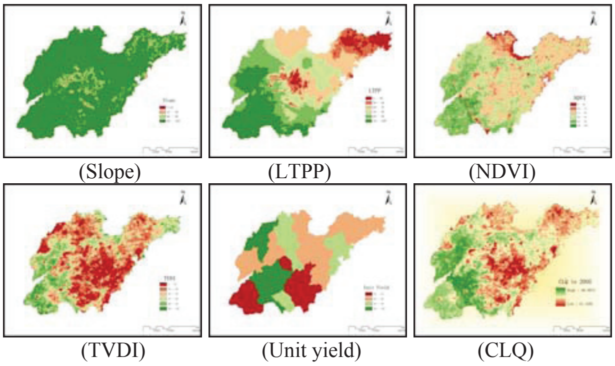

Fig.3 Thematic maps of indicators and CLQ in 2005

3.2. Grading of assessment indicators

Cluster analysis was adopted to grade all indicators used to assess CLQ into different categories and the expert knowledge about the local conditions and cultivated land quality assessment graded them as listed below (TABLE I). A score within the range of [0,100] was assigned to an indicator via linear interpolation (Kalogirou, 2002).

TABLE I THE INDICATOR SYSTEM AND SCORES FOR A PARTICULAR INDICATOR VALUE IN THE ASSESSMENT

indicator	grade	score	indicator	grade	score
Slope	≤2	100-98	**LTPP**	≤51940	0-40
	2-6	98-80		51940-54242	40-60
	6-15	80-45		54242-56253	60-70
	≥15	≤45		56253-57832	70-80
				57832-59436	80-90
				≥5943	90-100
NDVI	≤0.189	0-60	**TEDI**	≤0.282	95-100
	0.189-0.427	60-75		0.282-0.469	85-95
	0.427-0.556	75-90		0.469-0.615	70-85
	0.556-0.659	90-95		0.615-0.744	60-70
	0.659-0.768	95-98		0.744-0.865	40-60
	≥0.768	95-100		≥0.865	0-40
Unit yield (2000)	≤4501	50-65	**Unit yield (2005)**	≤5515	50-65
	4501-5066	65-80		5515-5986	65-80
	5066-5818	80-90		5986-6362	80-90
	≥5818	90-100		≥6362	90-100

4.Results

Extracting cultivated land from the assessment result as listed below:

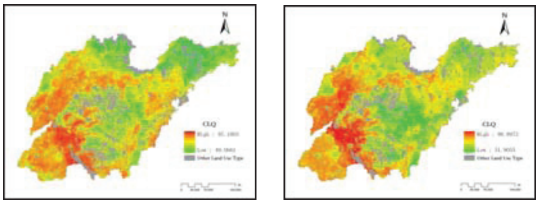

Fig.4 Thematic maps of CLQ in 2000(left) and 2005(right)

The spatial framework of cultivated land in Shandong Province changed indistinctively from 2000 to 2005 (Fig.4). Thus cultivated land quality has been divided into three levels: high, medium and low. (I) The cultivated land with high quality is mainly distributed in southwest and most of the west in Shandong Province, where the condition of light-temperature is advantageous to agricultural development, and both soil fertility and moisture reflected by remote sensing index are better than other areas; (II) The quality of cultivated land ring-distributed around the central mountainous region is at the medium level due to the appropriate natural settings including slope, light-temperature, soil fertility and soil moisture. (III) The cultivated land quality of other parts in study area is lower. Northeast area is restricted by slope, light-temperature condition and soil moisture, while northwest area by soil fertility. Besides, with high altitude and steep slope, central mountainous area where cultivated land is limited and distributed fragmentarily is disadvantageous to farming because of all of indicators used to assess CLQ are lower than the average.

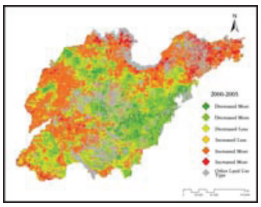

Fig.5 The variation of CLQ from 2000 to 2005

The overall quality of cultivated land in Shandong Province has declined slightly from the score of 80.22 in 2000 to 79.96 in 2005 although it has improved in some areas. The cultivated land quantity in the study area has increased by 269,015 hectare during the study period and the increased part is mainly distributed in the northeast and in the northwest in Shandong Province. The improvement of CLQ in the northeast and in the northwest is significant as a result of increasing soil fertility and soil moisture as well as the west and the north area in the study area. On the other hand, the decreasing soil moisture and unit yield led to the degeneration of CLQ in the east area. In spite of the increase of soil moisture, the CLQ has declined in the southwest from 2000 to 2005. It indicated that during the study period the quality of cultivated land in southwest influenced by farming system, input and so on did not make the most of the advantage of appropriate natural settings, so this area has more potential for agricultural development.

The result of CLQ assessment was graded based on pixel and city-level administrative division respectively by using the method of cluster analysis, then the table of CLQ assessment grade classification based on pixel (TABLE II) and the grade division map based on city (Fig.6) in both 2000 and 2005 was made.

TABLE II THE GRADE OF CULTIVATED LAND QUALITY

grade	score	area percentage in 2000(%)	area percentage in 2005(%)
Level 1(high)	87-100	24.41	24.07
Level 2(high)	80-87	35.69	29.35
Level 3(medium)	74-80	19.79	25.72
Level 4(low)	67-74	14.79	16.38
Level 5(low)	49-67	5.32	4.48

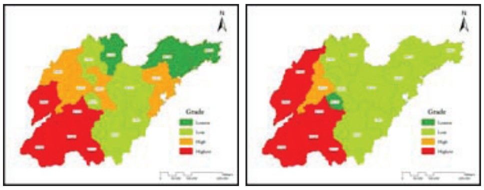

Fig.6 The city-level administrative map of CLQ grade

As illustrated in Table 2, the quality of most cultivated land in Shandong Province is at the level more than medium. For example, the quantity of cultivated land whose quality is more than or equal to average is 79.89% and 79.14% of total cultivated land in 2000 and 2005 respectively, which means that high quality of cultivated land in Shandong Province ensured the good development momentum of agriculture. The gap between high quality cultivated land and that of low quality narrowed from 2000 to 2005. Furthermore the standard deviation of grade has declined from 8.23 to 8.12. The conversion from high quality to low quality is more than it from low quality to high quality, particularly the conversion from level 2 to level 3, which is the reason why the overall quality of cultivated land in Shandong Province has declined slightly.

From the viewpoint of city-level administrative division, the quality of cultivated land in southwest occupied the first place, west second, central and east area third and northeast and northwest the worst. The quality of cultivated land in Dezhou, Dongying, Yantai and Weihai increased by one level. By contraries, in Qingdao, Zibo and Laiwu, it decreased by one level mainly because that the total area of cultivated land in these cities is so small that the area-weighted CLQ is unstable.

5. Conclusion

This paper establishes a proper framework used to assess CLQ from the perspective of pressure, state and response; they are represented by five indicators: slope, light-temperature potential productivity, NDVI, TVDI and unit yield. The result of CLQ assessment was summarized as follows: 1) The quality of cultivated land in Shandong Province decreased from the southwest to the northeast as a whole; 2) The overall quality of cultivated land in Shandong Province has declined slightly from 2000 to 2005, but at the high level; 3) The quality of cultivated land in some areas with proper natural settings is low instead of being high as Heze is such area. With appropriate geographical and light-temperature conditions, at the high level of soil fertility and soil moisture, the cultivated land in Heze, however, lags behind the average, indicating the low utilization efficiency and high development potential; 4) The CLQ and the economic development level are inconsistent in some areas in Shandong Province.

Acknowledgment

This research is supported by the National Science and Technology Support Program (2008BAH31B04) named "Decision support technology and system integration research of the national main functional regions planning project (2008BAH31B04)". Its support is gratefully acknowledged.

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